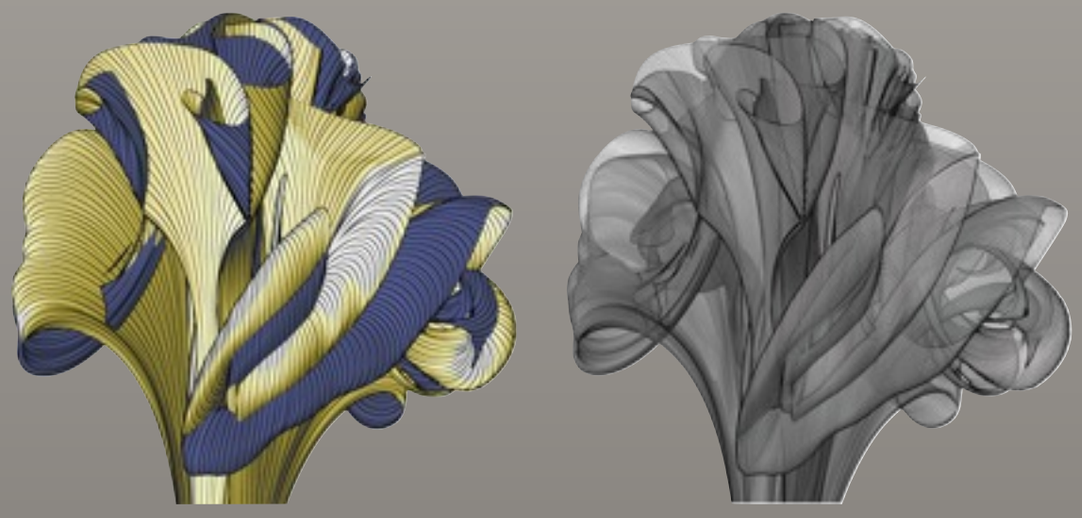
Integration-Based Flow Visualization Beyond Streamlines

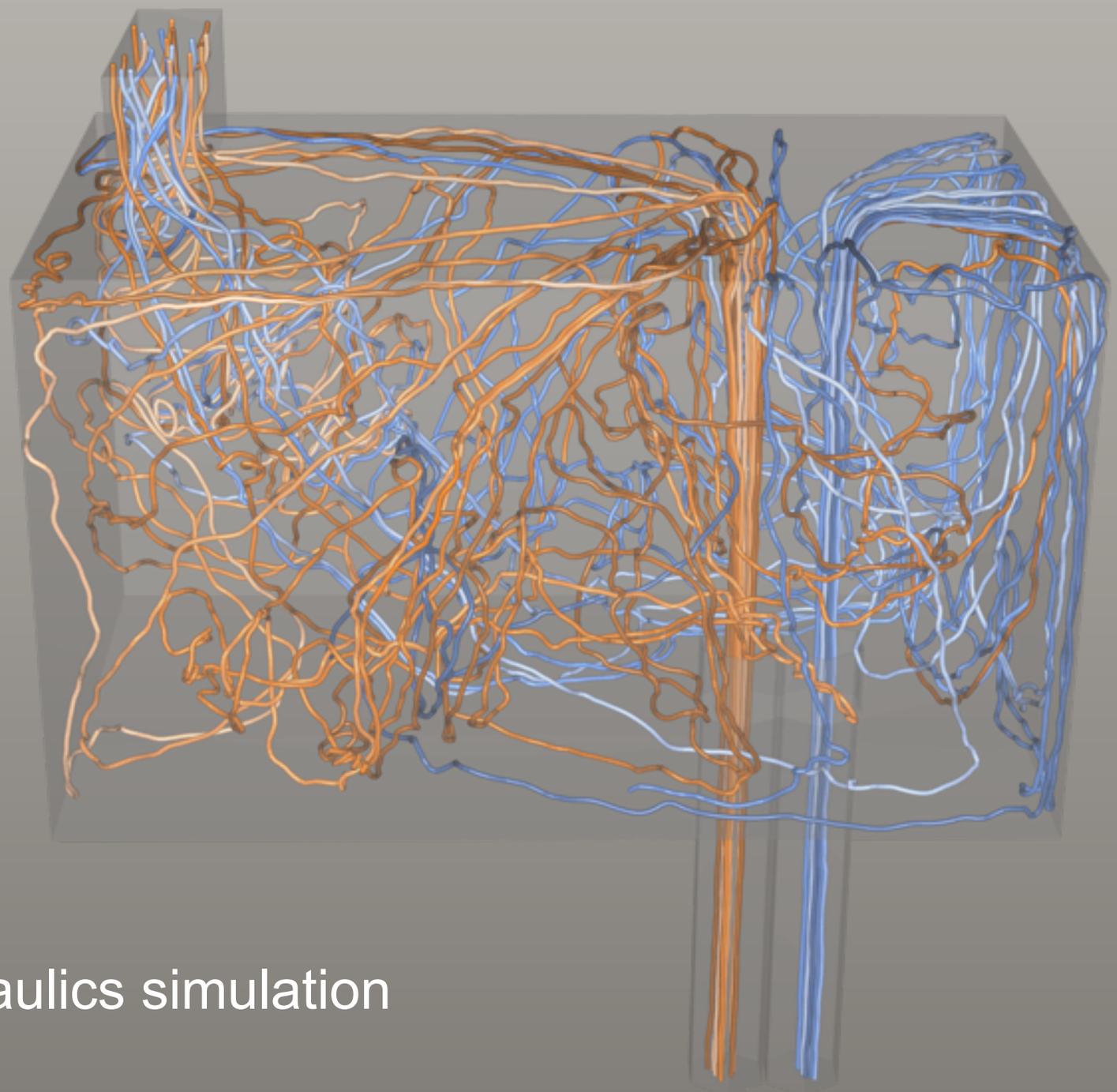
Christoph Garth
UC Davis



E. WES BETHEL (LBNL), CHRIS JOHNSON (UTAH), KEN JOY (UC DAVIS), SEAN AHERN (ORNL), VALERIO PASCUCCI (LLNL), JONATHAN COHEN (LLNL), MARK DUCHAINEAU (LLNL), BERND HAMANN (UC DAVIS), CHARLES HANSEN (UTAH), DAN LANEY (LLNL), PETER LINDSTROM (LLNL), JEREMY MEREDITH (ORNL), GEORGE OSTROUCHOV (ORNL), STEVEN PARKER (UTAH), CLAUDIO SILVA (UTAH), XAVIER TRICOCHE (UTAH), ALLEN SANDERSON (UTAH), HANK CHILDS (LLNL)

www.vacet.org

Integration-Based Vis Example



Streamlines

"Fishtank" thermal hydraulics simulation
P. Fischer, ARNL

Summary

<u>What's the problem?</u>
Increasing demand for advanced integration-based visualization techniques to solve real-world visualization problems.

<u>What did we do?</u>

1. Robust, efficient methods for integration
   - Large data, parallel + distributed, real-world data representations
2. New techniques and algorithms
   - Integral Surfaces, Lagrangian Methods
3. Visualization approaches
   - Flow Illustration, Automated Seeding, Interactive Techniques

<u>What is the impact?</u>
Enable integration-based methods as a much-needed production visualization tool for scientists.

Research Roadmap

- Efficient and Flexible Computation of Integral Curves
  - Parallel / distributed computation → Dave P.'s and Dave C.'s talks
  - Over real-world data representations (unstructured, AMR) → Eduard's talk
- Advanced Visualization: Lagrangian Methods
- Advanced Visualization: Integral Surfaces
  - Robust, efficient computation algorithms for integral surfaces
  - Flow Illustration
- Applications
  - Flow Structure Visualization / Hypothesis Testing (various)
  - Integral Curve Statistics and Queries → Hank's talk
  - Medical Visualization (with Siemens Medical Research)
  - Always: Deployment to scientific communities through VisIt

Integration over Unstructured Meshes

Streamlines over Unstructured Meshes

- Interpolation over unstructured meshes is hard
  - need to find candidate cells that contain interpolation point ("cell location" problem)
  - typical data structures: octree (VTK), kd-tree, interval tree (VisIt)

- Available solutions (really only VTK)
  - do not work well with adaptive, large meshes
  - are complicated to work with

Streamline over Unstructured Meshes

New data structure: “CellTree”

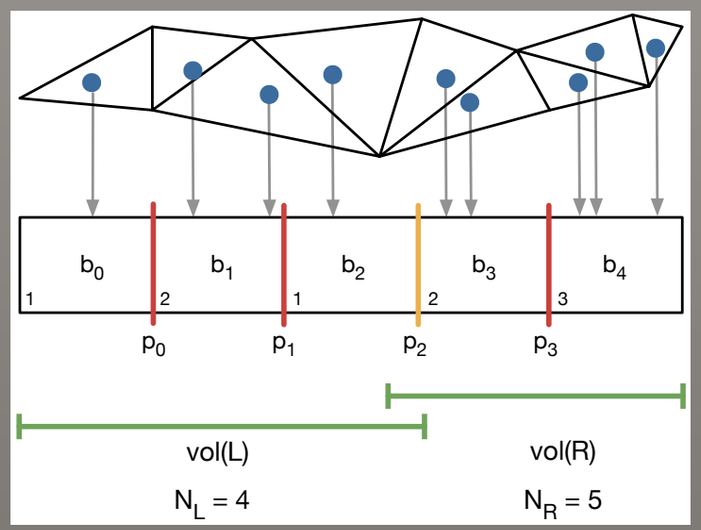
In a nutshell:

1. Efficiently implemented interval tree

2. Heuristic cost function for “good” splits

$$C = vol(L) \cdot N_L + vol(R) \cdot N_R$$

3. Fast recursive splitting through bucketed cost function analysis



Streamlines over Unstructured Meshes

New data structure: “CellTree”

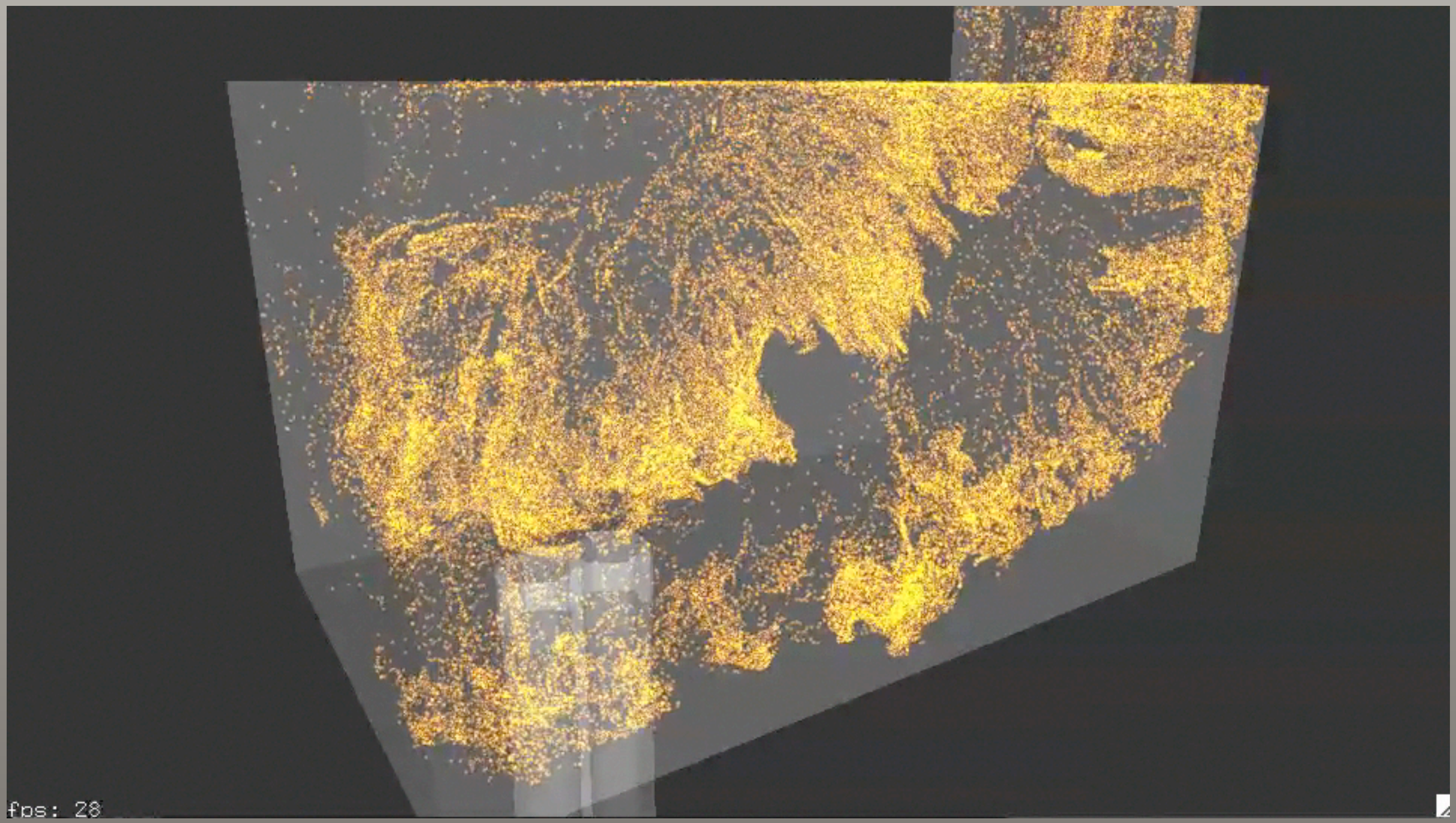
Great results for a drop-in replacement for vtkCellLocator.

Impact:

- Reliable, fast interpolation over unstructured meshes.
- Facilitates integration-based methods on larger, more comple data
- Aimed at CPU, but fully GPU-capable (interactive visualization)

Dataset	Locator	Build time	Memory Overhead	Random	Plane	Volume	Streamlines
Ellipsoid	*vtkCellTree*	3.34s	22MB (8%)	4.32s	1.91s	11.58s	1.70s
	vtkCellLocator	0.61s	90MB (34%)	7.71s	75.68s	559.98	–
	vtkModifiedBSPTree	6.72s	236MB (91%)	30.37s	1.90s	116.33s	46.39s
ICE	*vtkCellTree*	3.27s	23MB (13%)	2.51s	1.68s	6.42s	2.66s
	vtkCellLocator	0.53s	115MB (65%)	5.95s	89.93s	57.65s	211.45s
	vtkModifiedBSPTree	7.65s	246MB (140%)	16.90s	13.43s	69.67s	43.57s
BMW	*vtkCellTree*	40.25s	229MB (14%)	2.34s	3.57s	8.94s	1.97s
	vtkCellLocator	5.01s	921MB (56%)	5.15s	–	–	–
	vtkModifiedBSPTree	303.23s	2476MB (151%)	–	–	–	–
TDELTA	*vtkCellTree*	28.08s	165MB (14%)	1.66s	4.65s	9.48s	25.33s
	vtkCellLocator	4.2s	880MB (79%)	3.99s	–	–	–
	vtkModifiedBSPTree	77.57s	1770MB (159%)	61.86s	–	–	–
Fishtank	*vtkCellTree*	27.59s	196MB (8%)	3.52s	3.79s	6.85s	27.11s
	vtkCellLocator	6.16s	851MB (35%)	7.74s	12.04s	40.04s	28.75s
	vtkModifiedBSPTree	199.41s	2162MB (91%)	–	–	–	–
F6	*vtkCellTree*	130.19s	743MB (16%)	1.59s	8.96s	17.63s	9.60s
	vtkCellLocator	22.40s	5426MB (124.54%)	5.80s	–	–	–
	vtkModifiedBSPTree	–	–	–	–	–	–

GPU-based Unstructured Flow Vis



Unstructured Meshes

New data structure: “CellTree”

Planned integration into VisIt:

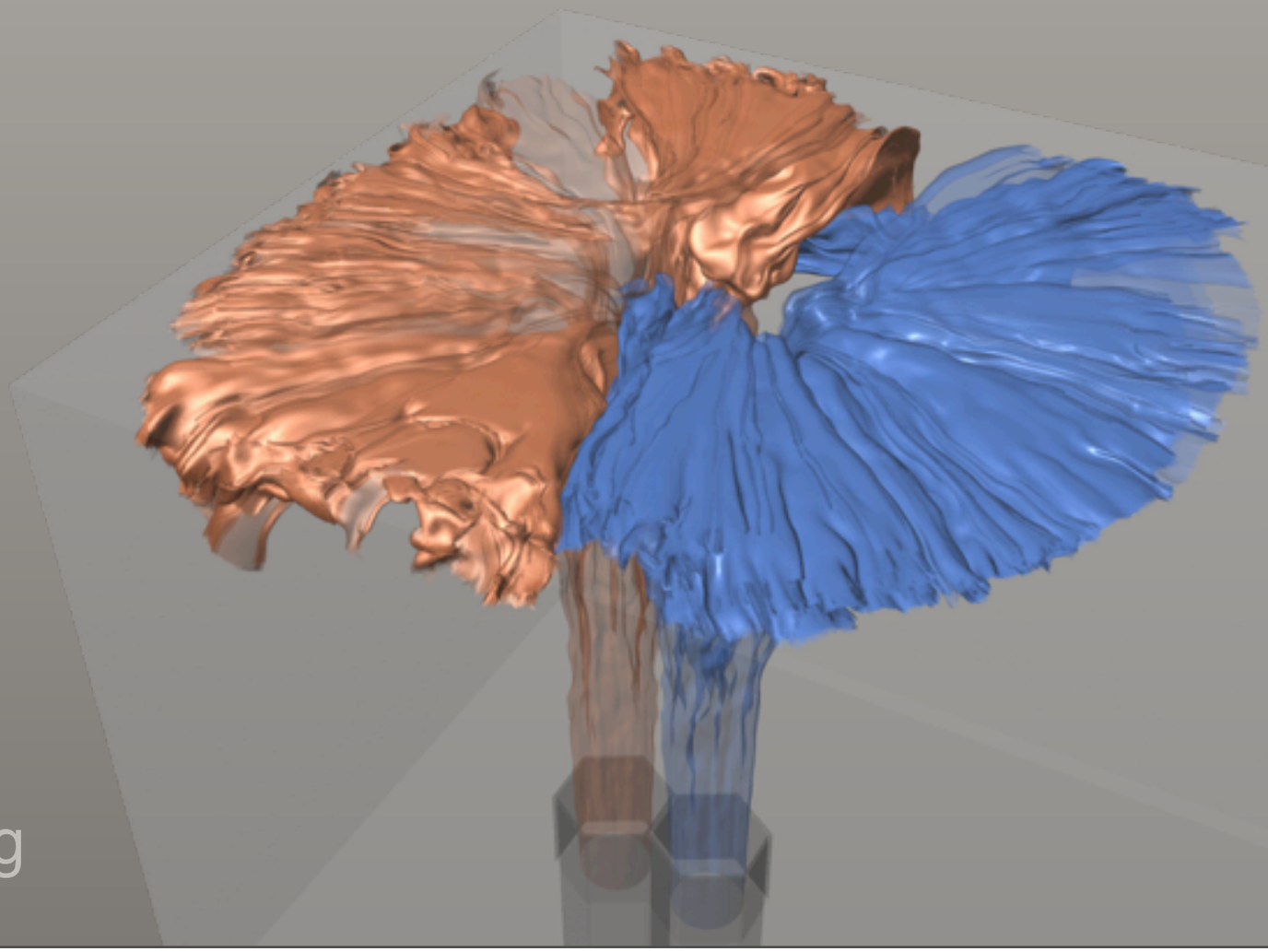
- easy since drop-in for vtkCellLocator already implemented
- further improves VisIt’s integration-based infrastructure, makes this available to any VisIt user in the next release

Flow Illustration

Illustrative Rendering for Integral Surfaces

Integral Surfaces: visualization / flow illustration tool

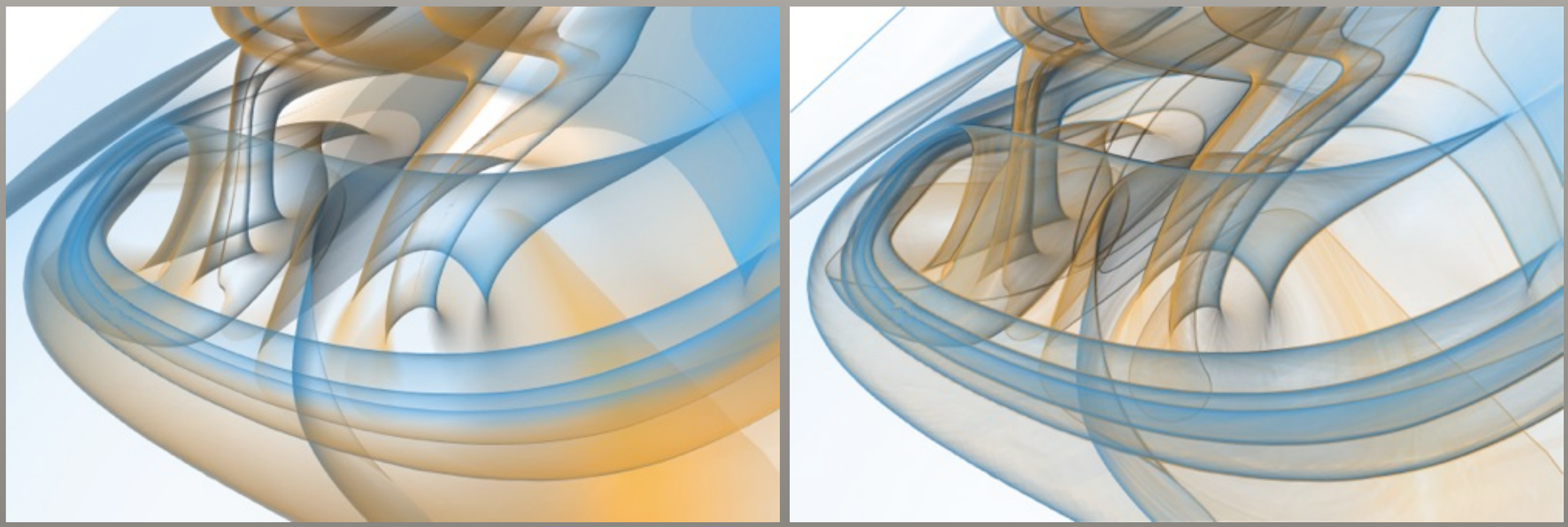
Goal: one image to explain, illustrate and communicate complicated flow behavior.



www.vacet.org

Illustrative Rendering for Integral Surfaces

Integral Surfaces + Illustrative Rendering Techniques: Curvature-Based Transparency

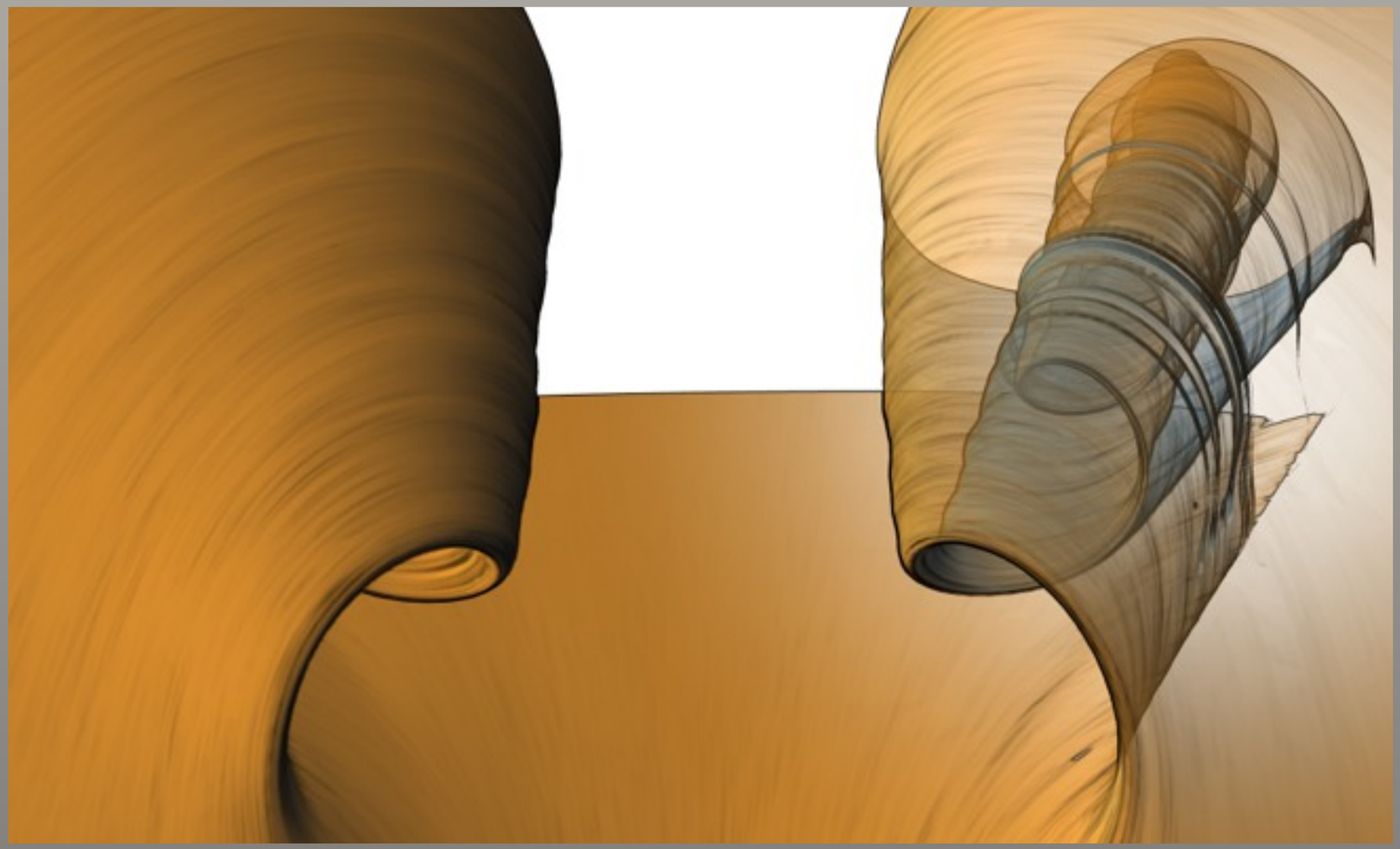


"Flow around Ellipsoid"
M. Rütten, DLR Germany

www.vacet.org

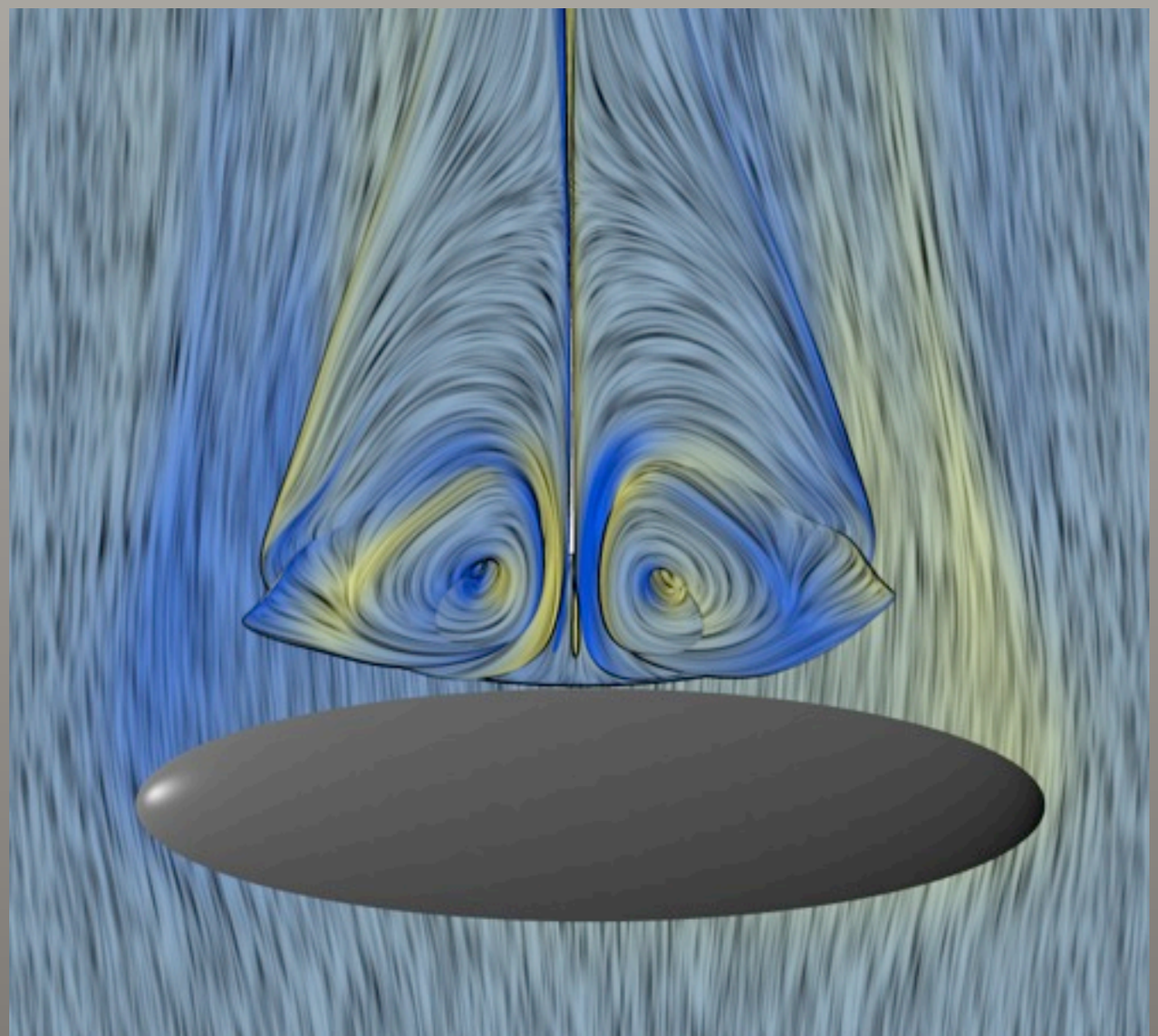
Illustrative Rendering for Integral Surfaces

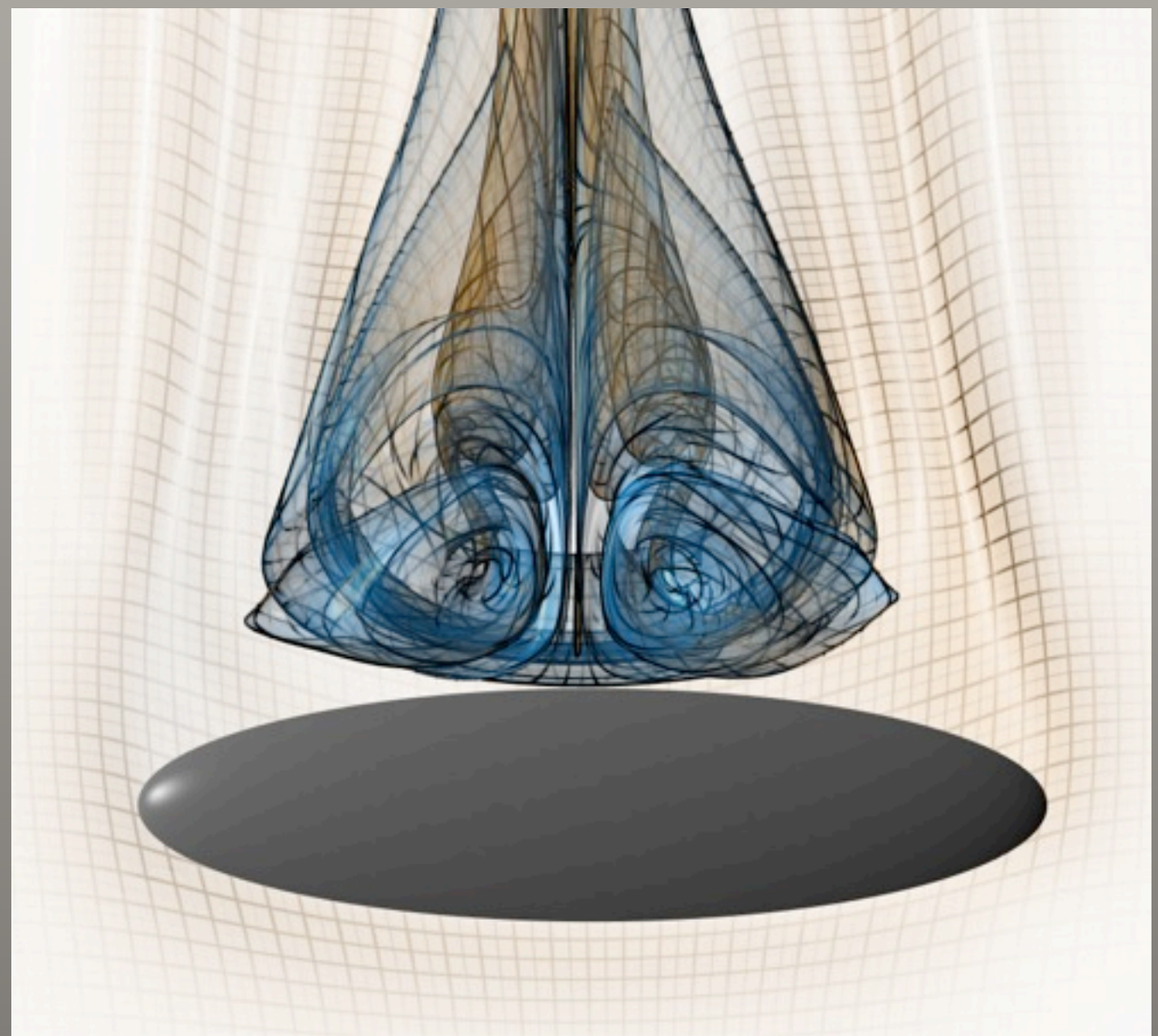
Integral Surfaces + Illustrative Rendering Techniques: Windowed Transparency



Illustrative Rendering for Integral Surfaces

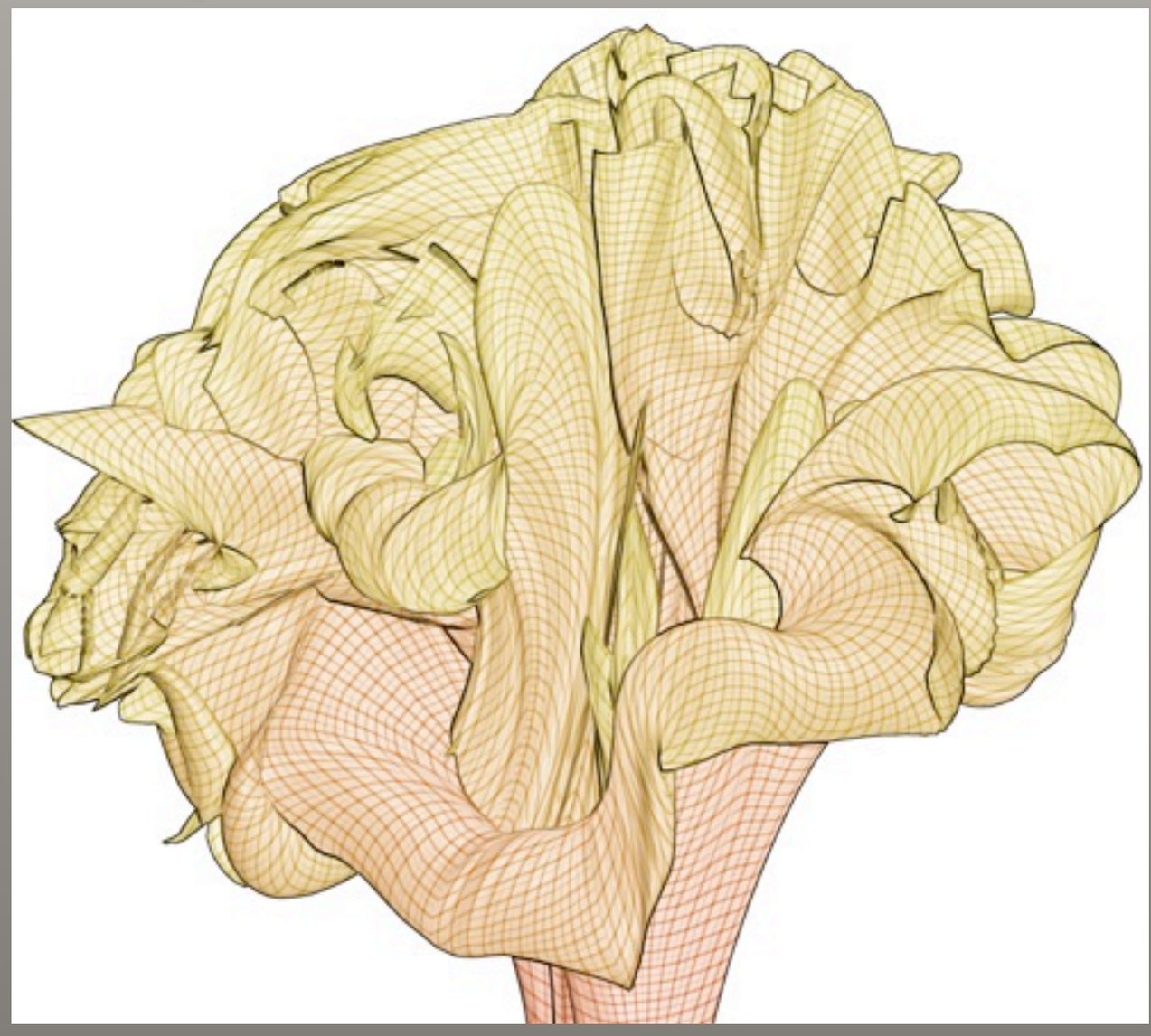
Integral Surfaces + Illustrative Rendering Techniques:
Distortion-free and resolution-independent texture-mapping





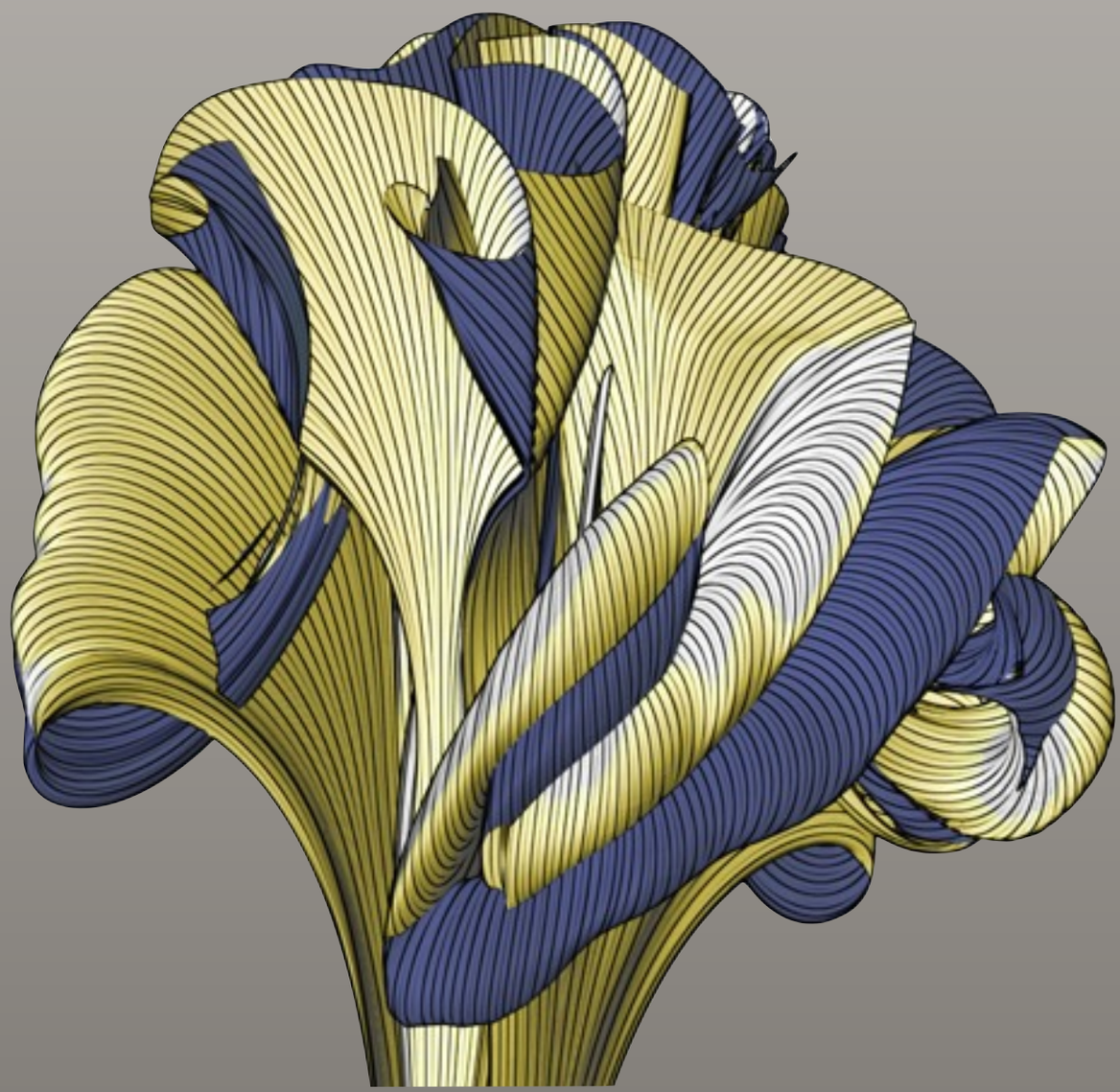
Illustrative Rendering for Integral Surfaces

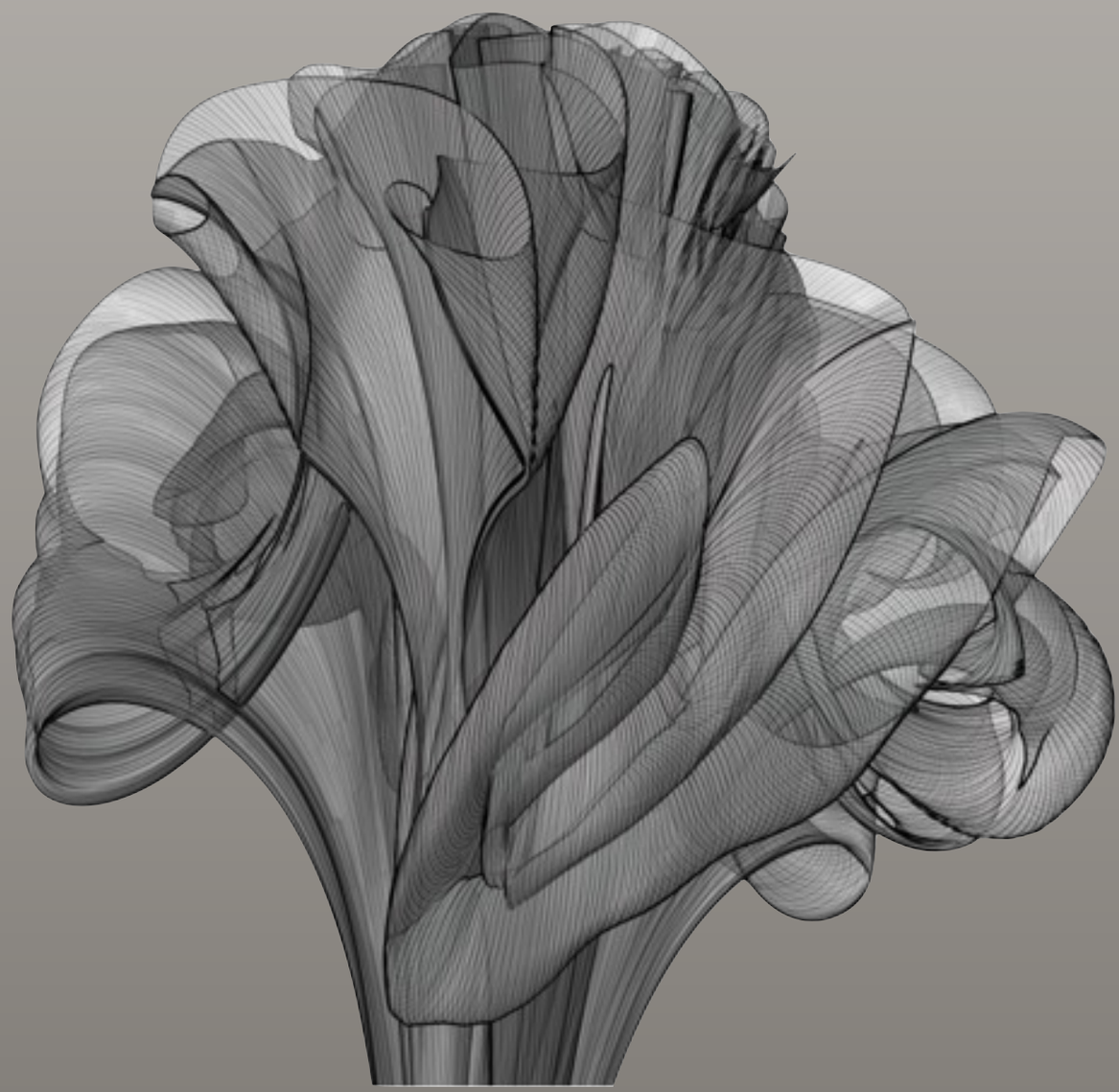
Integral Surfaces + Illustrative Rendering Techniques: Distortion-free and resolution-independent textures



Illustrative Rendering for Integral Surfaces

Integral Surfaces + Illustrative Rendering Techniques:





Illustrative Rendering for Integral Surfaces

Integral Surfaces + Illustrative Rendering Techniques

Have a working real-time rendering pipeline, would like to integrate into VisIt.

Impact:
Give scientists an effective visualization / communication tool for flow structures.

One picture to illustrate complex 3D structures that were very hard or impossible to visualize before.

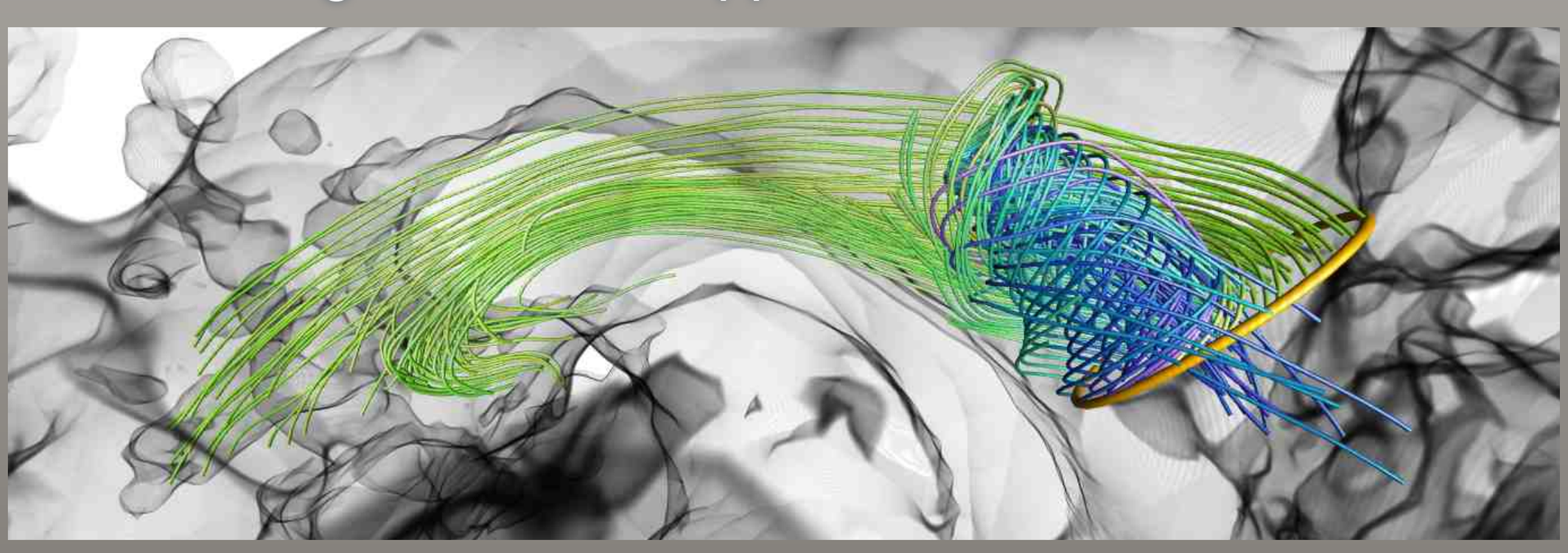
Lots of interest from application scientists.

Medical Visualization

Application: Medical Visualization

Collaboration with Siemens Medical Research on 7D-MRI (simultaneous anatomy & velocity acquisition, time-dep.)

Impact: New flow analysis capabilities to support diagnosis, robust enough for clinical application



VACET-funded R&D translates to other domains

Application: Medical Visualization

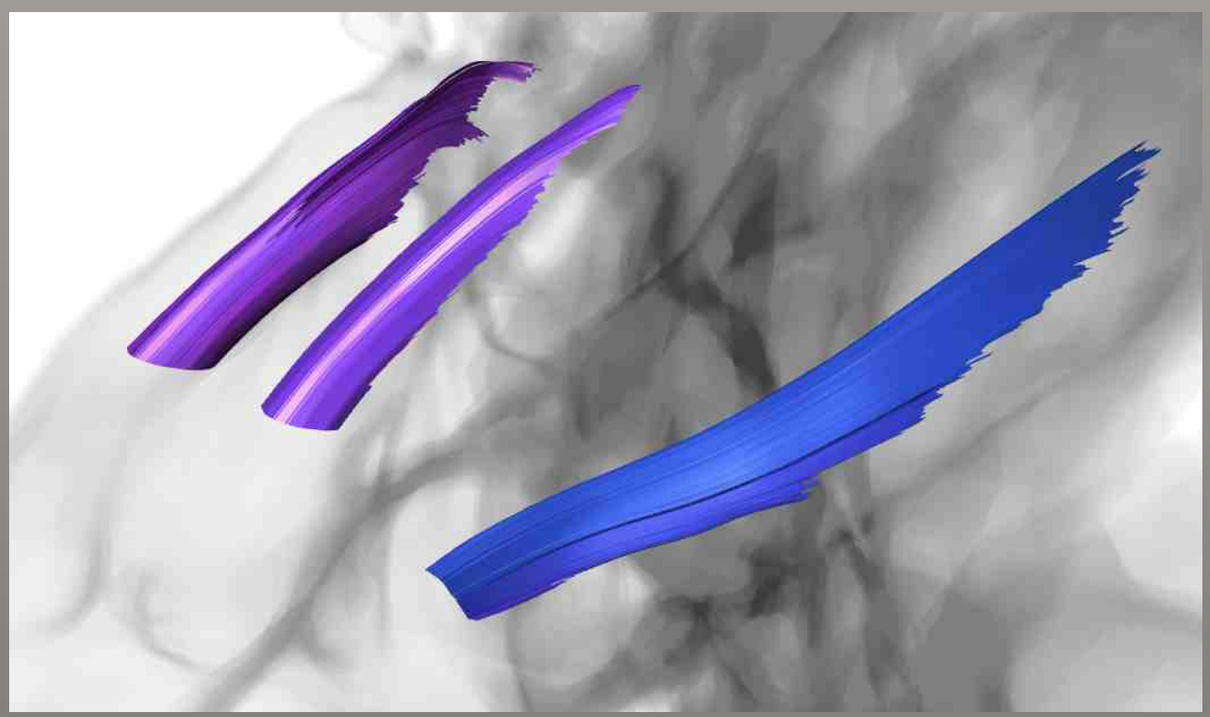
Collaboration with Siemens Medical Research on 7D-MRI
(simultaneous anatomy & velocity acquisition, time-dep.)

Finite-Time Lyapunov Exponents:
Improved, flow-based vessel boundary segmentation

Application: Medical Visualization

Collaboration with Siemens Medical Research on 7D-MRI
(simultaneous anatomy & velocity acquisition, time-dep.)

Finite-Time Lyapunov Exponents:
Improved, flow-based vessel boundary segmentation

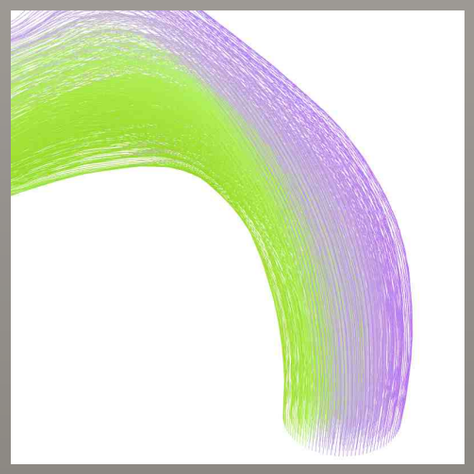
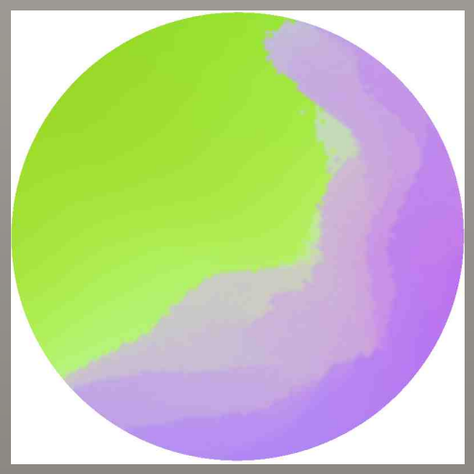
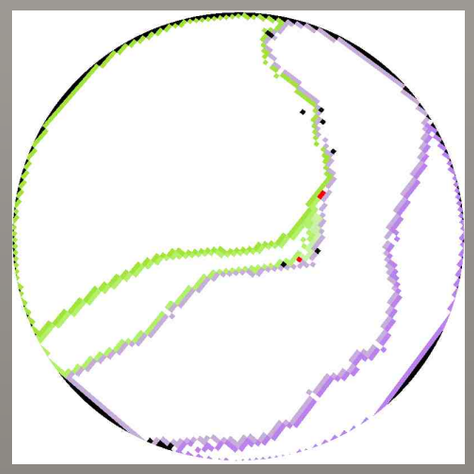
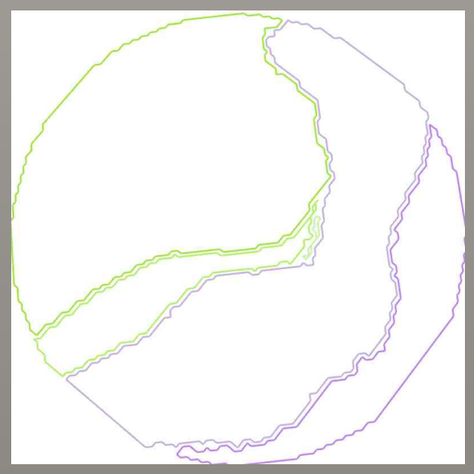
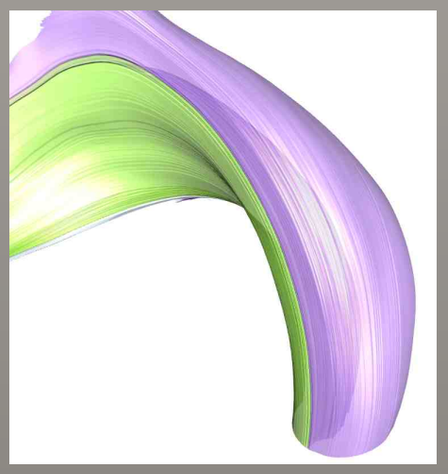


Application: Medical Visualization

Collaboration with Siemens Medical Research on 7D-MRI (simultaneous anatomy & velocity acquisition, time-dep.)

Segmentation of flow through a vessel cross-section

Path surfaces to visualize different flow components

Outlook

What are plans for the future?

1. More robust, efficient methods for integration
   - hybrid parallelism, ease-of-use improvements, ...
2. New techniques and algorithms
   - Lagrangian Methods + Topology (with SCI/LLNL group), ...
3. Visualization Approaches
   - Automated Seeding, In-situ Integral Surfaces
4. Deployment + More Applications
   - Want everything shown available in VisIt